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DEPARTMENT OF THE INTERIOR
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JOSEPH A. HOLMES, DIRECTOR

THE RATE OF BURNING OF FUSE

AS INFLUENCED BY TEMPERATURE AND PRESSURE

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ENGINEERING
ENGIN STORAGE

BY

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THE RATE OF BURNING OF FUSE, AS INFLUENCED BY TEMPERATURE AND PRESSURE.

By Walter O. Snelling and Willard C. Cope.

INTRODUCTION.

Miners' fuse, known also as "safety fuse," "running fuse," and "Bickford fuse," consists essentially of a core of gunpowder, surrounded by protective wrappins or coatings. It is used in blasting as a gunpowder "train" for transmitting ignition to the charge of explosive, and its purpose is to provide a time interval between the lighting of a "shot" and the explosion of the charge.

Such fuse best fulfills its purpose when its rate of burning[a] is uniform, so that the interval between the moment of lighting the "shot" and the moment at which the "shot" explodes is definite for any given kind and length of fuse. In mining operations it is assumed that the fuse used burns at a regular and uniform rate, and, believing this, the miner in his daily work cuts off such lengths of fuse as should give the particular time intervals desired.

There are, however, conditions that cause variations in the rate of burning of fuse, some causing a marked retardation and others causing a decided acceleration. Hence it has seemed necessary to investigate the conditions that bring about these variations, since any marked change in the rate of burning of fuse can cause an accident.

For instance, where a number of shots are to be fired in one round, it is not always possible to determine by the usual method of counting that every shot has fired. Hence, should one piece of fuse have been subjected to such conditions as produce a retardation in its rate of burning, the miner may go back to the shot before all the holes have fired and encounter an explosion as he nears the face. On the other hand, should conditions be such as to cause an increase in the rate of

[a] In this paper, the rate at which fuse burns is expressed in units of time, as "30 seconds per foot," and not in units of length, as "2 feet per minute," though the latter form is more in accord with ordinary usage in describing speed or motion. The reason for using the form "seconds per foot" or "seconds per meter" is that the time in which a given length of fuse burns is the information the miner desires.

burning of one piece of fuse out of a number used in a single round of holes, it may be possible for this piece of fuse to bring about an explosion before the miner has been able to light all of the other pieces and reach a point of safety.

It will thus be seen that either retardation or acceleration in the rate of burning of fuse can readily become the cause of accident, and accordingly the study of the conditions under which the rate of burning of fuse is so changed as to cause the fuse to burn more rapidly or more slowly becomes of particular importance.

Miners have frequently noticed that fuse, when surrounded by very dense stemming material, as in a hole that has been firmly tamped, burns faster than it should. In this case the dense and impermeable stemming prevents the free escape of the gases from the powder, and so compresses them in their attempt to escape as to bring about a decided quickening in the rate of burning. As the use of firm stemming is nearly always desirable, one can readily see that information as to the degree of quickening in the rate of burning of fuse under these conditions is essential in order that the miner may in such cases know what additional length of fuse is necessary to provide for the increased rate of burning.

Retardation in the rate of burning of fuse is a serious fault. Cases are known, though fortunately very few, in which a piece of fuse has seemingly stopped burning, and yet after an interval of one or more hours has brought about the explosion of the charge to which it was attached. Cases of this sort never happen with fuse that is in good condition, but may sometimes happen when fuse is of poor manufacture or has been subjected to unfavorable conditions of moisture or temperature.

The conditions that are believed to be most active in bringing about either a retardation or an acceleration in the rate of burning of time fuse have been investigated experimentally, and the results that have been obtained will be classified in this report under effects due to: (*a*) Pressure; (*b*) temperature; (*c*) moisture; (*d*) mechanical injury.

NATURE AND COMPOSITION OF FUSE.

Many varieties of fuse have been manufactured. They differ mainly in the nature of the protecting layers or coatings, or the manner in which the waterproofing is effected. In general, all types of fuse are similar in structure, and in all of them the essential element is a core of fine-grained gunpowder wrapped about by threads of hemp, jute, or cotton.

The fuse is made by a machine in which a number of jute threads, usually 10, are spun around the outlet tube of a hopper or funnel, through which the fine-grained gunpowder is descending. The outlet tube is so arranged in relation to the revolving cords (called the

"spinning threads") that the stream of gunpowder delivered from the hopper is caught within a channel of cord. A second set of threads (called "countering"), usually of cotton, is spun in the opposite direction around the first set that contains the powder core, and by means of these two sets of threads spun in opposite directions the core of fine powder is held in place, the twisted cords forming, in effect, a tube within which the powder is contained. Sufficient tension is kept upon the cords, during the operation of spinning, to insure their holding the core of gunpowder closely. No space not filled with gunpowder should be present.

DESCRIPTIVE TERMS.

There are several varieties of fuse made after the general method just described. In examining most of these types of fuse a fine thread, called the "center thread," will usually be found in the powder core. This thread passes through the hopper containing the powder, and its function is to cause the powder to pass in a constant stream through the small aperture at the bottom, and to prevent the clogging of the fine opening that delivers the stream of powder to the fuse that is being formed.

In referring to the various types of fuse, use will be made of the term "raw fuse" or "wrapped core" to describe the core of gunpowder surrounded by the spinning threads and first countering, as just described.

Fuse is divided into three main classes according to the nature of the work for which it is intended. Fuse of class 1 is suitable for dry work, such as stump blasting and quarrying. Fuse of class 2 is intended for damp or wet work, as in coal mining, or in surface work where mud, rain, or dampness is encountered. Fuse of class 3 is suitable for very wet work, such as may be necessary in tunneling, shaft driving, etc.

Cotton, hemp, and single-countered fuse are of the first type, and consist of "raw fuse" that has been drawn through a bath of waterproofing material and finished with whiting, talc, or some similar substance to prevent the separate loops of a coil from sticking together. In cotton fuse the spinning threads as well as the countering are of cotton instead of jute. Single-tape fuse and double-countered fuse are of the second type, and consist of raw fuse that has been twice coated with waterproofing material, double countered or taped, and finished like fuse of type 1. Double tape, triple tape, gutta percha, and taped double-countered fuse belong to the third type. These consist of raw fuse that has been coated with waterproofing material and taped or double countered, and then finished with a coating of black varnish and whiting or talc, etc., or with a heavy coating of white china clay mixed with glue to form a paste.

COMPOSITION OF FUSE POWDER.

The gunpowder which forms the core of safety fuse is usually in very fine grains. At times the waste from sporting powder is used in the preparation of fuse, but usually a special powder is made for this purpose. An analysis of a sample of fuse powder gave the following results:

Analysis of fuse powder.

Moisture	00.63
Nitrate of potash	74.42
Sulphur	11.96
Charcoal	12.99
	100.00

The size of the grains of this powder as determined by a sieve test was as follows:

Size of grains of fuse powder.

Caught on 40-mesh sieve	7.71
Caught on 60-mesh sieve	40.53
Caught on 80-mesh sieve	13.95
Caught on 100-mesh sieve	27.50
Through 100-mesh sieve	10.31
	100.00

RATE OF BURNING OF TIME FUSE.

The rate of burning of fuse depends in some measure upon the composition of the gunpowder that is used. Experiments that have been made with fuse powder for military use[a] show that an increase in the percentage of potassium nitrate increases the rate of burning, whereas an increase in the percentage of charcoal decreases the rate of burning. With powder of the composition ordinarily used in the manufacture of fuse, an excess of either charcoal or potassium nitrate will have a retarding effect upon the rate of burning of the resulting fuse, and the same tendency will result from imperfect incorporation of the constituents of the powder. The addition of inert substances, such as brick dust or talc in finely powdered form, also decreases the rate of burning of fuse powders. It has been noted, too, that decrease in the size of the grain of a gunpowder used in fuse may decrease the rate of burning.

In order to determine the effects due to a difference in the granulation of the powder used in fuse there were made up, through

[a] Dolleczek, Anton, Fuse powder, Jour. Frank. Inst., vol. 170, p. 269.

the courtesy of the manufacturer, some samples of fuse that were prepared upon the same machine but contained powder that had been separated by means of sieves so as to obtain samples of different granulation. In these experiments the fuse was of the double-tape variety; in sample 1 the powder used was that portion which would pass through a sieve of 80 meshes to the inch, sample 2 contained powder which passed through a 60-mesh sieve but was caught upon an 80-mesh sieve, and the powder of sample 3 passed through a 40-mesh sieve but was caught upon a 60-mesh sieve. The time of burning of each of these samples of fuse is shown in the following table:

Effect of powder granulation on rate of burning.

No.	Mesh.	Rate of burning.	
		Seconds per meter.	*Seconds per foot.*
1.....	80	82.3	25.1
2.....	60–80	77.3	23.5
3.....	40–60	76.3	23.2

The above table shows that fuse made from the finer powder burns somewhat more slowly than fuse in which coarser powder is used.

The density of the powder used in fuse probably has little influence upon its time of burning, although powders of high density burn at a more regular rate than those of low density.

Attention has already been called to the fact that tension is applied to the spinning threads which, in the manufacture of the powder core of safety fuse, form the first wrapping. This is an extremely important fact, as when gunpowder is placed within a tube that it only partly fills (leaving a more or less extensive air space), the rate of burning is much more rapid than when the tube is completely filled with the powder. A type of so-called instantaneous fuse is, in fact, made upon this principle by leaving a considerable air space in the core throughout the entire length of the fuse. Such fuse burns at the rate of about 150 meters (492 ft.) per second.

The amount of gunpowder used in fuse, as well as the amount of tar, asphalt, or other waterproofing compound, varies rather widely in different types of fuse. The average amount of gunpowder found in several types of commercial fuse varies from 4.67 grams per meter (22 grains per ft.) to 5.10 grams per meter (24 grains per ft.)

The relative percentage (by weight) of the different parts of triple-tape fuse is indicated in the following table:

Powder	15.2
Waterproofing	46.2
Cords and wrapping	38.6
	100.0

In the burning of this and similar types of fuse much smoke is produced. This smoke in part is due to the solid residue from the gunpowder, but a very large percentage thereof consists of volatilized tar and its decomposition products from the covering of the fuse. A piece of fuse was tested and found to lose 23.14 per cent in weight upon burning. As the gunpowder within this fuse represented only 15.21 per cent of the total weight, it will be seen that at least 7.93 per cent represented volatilized tar and other decomposition products of the wrappings of the fuse. Owing to the large amount of carbonaceous material present in the wrappings, the gases produced by the burning of fuse consist largely of carbon monoxide. When large amounts of fuse have been burned, as in magazines where coils of fuse have caught fire, these gases have been found to be particularly suffocating and poisonous. An analysis of the gases produced by the burning of 100 feet of fuse gave the following results:

Analysis of gas produced by the burning of fuse.

[A. L. Hyde, analyst.]

Hydrogen sulphide	0.8
Carbon dioxide	32.7
Oxygen	1.4
Carbon monoxide	23.4
Hydrocarbons	4.1
Nitrogen	23.8
Hydrogen	13.8
	100.0

The quantity of gas produced was 103.3 liters, or 3.39 liters per meter of fuse (1.033 liters per foot of fuse).

NORMAL RATE OF BURNING.

The several varieties of fuse manufactured have, in general, individual rates of burning, which in any particular type of fuse are usually very constant under normal conditions, but vary considerably between different types of fuse.

A large number of tests have been made with a view of obtaining information regarding the average rate of burning of fuse of different kinds and the regularity in the rate of burning of fuse of each particular type. The records of these tests are too extensive to be given in full in a report of this nature, therefore, except in those individual cases where the timing tests have brought out variations, the tables given represent average results.

To determine the normal rate of burning of triple-tape fuse 14 samples were taken from separate rolls, and from each sample a trial

length of 1 meter was cut. The time of burning of these samples is given in the following tabulation:

Normal rate of burning of triple-tape fuse (1-meter lengths).

No. of sample.	Rate of burning.	
	Seconds per meter.	*Seconds per foot.*
1	82	25
2	87	27
3	83	25
4	87	27
5	85	26
6	84	26
7	85	26
8	84	26
9	87	27
10	85	26
11	84	26
12	85	26
13	85	26
14	86	27
Maximum	82	25
Minimum	87	27
Average	85	26

In order to determine whether the uniformity shown in the above table would continue when longer lengths of fuse were taken for tests, a series of experiments was carried out upon entire rolls of fuse (50 feet, or $15\frac{1}{4}$ meters), with results as follows:

Normal rate of burning of triple-tape fuse (50-foot lengths).

No. of sample.	Rate of burning.	
	Seconds per meter.	*Seconds per foot.*
1	76	23
2	77	23
3	80	24
4	82	25
5	84	25
6	85	26
7	85	26
Maximum	76	23
Minimum	85	26
Average	81	24.5

The uniformity in the rate of burning of the above samples is very marked, but it should be mentioned that all of the rolls tested were the product of a single factory, and were made at about the same time. Evidently, where fuse is made from one lot of powder and with tape, cord, etc., from a single purchase, the product would naturally be more uniform than where fuse is made up at different times, from different lots of powder, and with different mixes of asphalt composition, etc.

In the testing work of the Bureau of Mines, records have been taken regarding the average rate of burning of triple-tape fuse purchased by the Isthmian Canal Commission for use in work on the

Panama Canal, and as these records cover samples taken from every shipment purchased during a period of several years, the figures show such variations as have occurred in fuse of this type during that period. The results of such timing tests of triple-tape fuse for a period of one year, before the rate of burning had been accurately adjusted, are given in the following tabulation:

Rate of burning of triple-tape fuse purchased for use of Isthmian Canal Commission.

No. of sample.	Rate of burning.	
	Seconds per meter.	*Seconds per foot.*
1	79.4	24.2
2	80.4	24.5
3	81.4	24.9
4	81.7	25.0
5	80.4	24.5
6	75.6	23.0
7	68.9	21.0
8	73.5	22.4
9	74.1	22.6
10	78.7	24.0
11	78.7	24.0
12	71.5	21.8
13	84.0	25.6
14	81.0	24.8
15	79.7	24.3
16	86.6	26.4
17	88.9	27.1
18	83.0	25.3
19	81.4	24.9
Maximum	68.9	21.0
Minimum	88.9	27.1
Average	79.6	24.2

It will be noted that in the period of one year covered by this table the average rate of burning was 79.6 seconds per meter (24.2 seconds per foot). The maximum rate of burning was 68.9 seconds per meter (21 seconds per foot), and the minimum rate of burning was 88.9 seconds per meter (27.1 seconds per foot). The maximum rate of burning shows an increase of 15.1 per cent over the average rate of burning. The minimum rate of burning shows a decrease of 11.7 per cent from the average rate of burning. These variations are greater than prevail in the best brands of safety fuse manufactured at the present time.

Separate samples of fuse of the same type should not show variations greater than 10 per cent above, or 10 per cent below, the average rate of burning. Variations up to 10 per cent above or below the average rate of burning are not excessive, and are only such as might be expected in any commodity manufactured upon a commercial scale, with the necessary slight variations in the materials used, and in the other conditions of manufacture.

In subsequent parts of this paper, where the variations produced by temperature and pressures on fuse are considered, the variations noted in the above table will be shown to be very small as compared

with such changes in rate of burning as can easily be brought about by comparatively slight differences of temperature and pressure. It will be noted also that some of the variations found in the above table can probably be accounted for by the fact that the timing tests on this fuse were made at different periods of the year, and differences of temperature in the outside air as well as differences in barometric conditions could bring about small variations in the rate of burning.

The normal rate of burning of several types of fuse is shown in the following tabulation:

Normal rate of burning of several types of fuse.

Kind of fuse.	Rate of burning.	
	Seconds per meter.	*Seconds per foot.*
Cotton	85.0	25.9
Hemp	105.0	32.0
Single tape	99.0	30.0
Double tape	101.0	30.8
Triple tape	91.8	28.0
Yellow finished, double-countered fuse	104.0	31.6
Black finished, double-countered fuse[a]	131.5	40.0
White finished, double-countered, gutta-percha fuse[a]	106.0	32.3
White finished, double-countered fuse[a]	111.5	34.0
White finished, taped, double-countered fuse (Brand C)	81.2	25.0
White finished, taped, double-countered fuse (Brand A)	100.0	30.4
White finished, double-countered, gutta-percha fuse	99.0	30.0

[a] European manufacture.

INFLUENCE OF PRESSURE.

A considerable volume of permanent gases is produced by the burning of the gunpowder that forms the core of all types of time fuse. It is evident that if a considerable length of fuse lies within a shot hole, and if the stemming that is used around it is so impervious as to prevent the escape of the gases produced, or to allow their escape only with extreme difficulty, then the pressure upon the fuse will increase greatly.

In order to give some idea of the amount of gas that is produced in the burning of fuse, it may be stated that 1 cubic centimeter of such gunpowder as is used in time fuse will produce, on burning, 380 cubic centimeters of permanent gas. In 1 meter of fuse there are present about 4 grams of powder, or approximately 3.4 cubic centimeters, and accordingly the permanent gases from the burning of 1 meter of fuse should amount to 1,300 cubic centimeters. In the burning of fuse, however, gases are produced not only from the powder core, but also through distillation of the wrappings and the tar or other waterproofing compound, and the actual amount of gas produced by the burning of the fuse is greatly in excess of the volume named. From experiments made by burning fuse in a closed vessel

it has been found that 1 meter of fuse produces 3,388 cubic centimeters of permanent gas.

The first experiments made to determine the effect of pressure upon fuse were carried out within a cylindrical vessel 20.5 centimeters (8 inches) in diameter, within which any desired pressure up to 4 kilograms per square centimeter (60 pounds per square inch) could be produced. This cylinder was provided with a removable head, by means of which rolls of fuse could be inserted or removed, and this removable head was provided with gaskets to insure the cylinder being gas-tight. The arrangement of the cylinder was such that the desired pressures could be produced when the cylinder was filled either with air or with water, so that the influence of pressure upon the rate of burning could be determined either when the fuse was suspended in air or was submerged in water. The cylinder was provided with a pressure gage reading up to 20 atmospheres (approximately 20 kilograms per square centimeter, or 300 pounds per square inch) and with a relief valve by which the pressure within the cylinder could be reduced at any time, so that the excess gases produced by the combustion of the fuse could be allowed to escape and the pressure within the vessel be kept constant during the experiment.

Pieces of fuse 3 meters in length were taken, and a 3X blasting cap or detonator was affixed to one end of each piece of fuse. At the other end an electric igniting device was attached, so that by passing an electric current through the wires that entered the cylinder the ignition of the fuse could be brought about. When the fuse burned through to the detonator the resulting report could be readily heard, and the time between the moment the electric igniter was fired and the final report of the detonating cap was taken by a stop watch.

The first experiment made was with triple-tape fuse that, burning under normal conditions, had been found to have an average rate of burning of 91.8 seconds per meter (28 seconds per foot). The rate of burning of four samples of this fuse at an indicated pressure of 1 kilogram to the square centimeter (approximately 15 pounds per square inch) was as shown in the following table:

Rate of burning of triple-tape fuse under 1 atmosphere pressure.[a]

No. of sample.	Rate of burning.	
	Seconds per meter.	*Seconds per foot.*
1	35.1	10.7
2	59.0	18.0
3	63.3	19.3
4	63.9	19.5
Average	55.4	16.9
Normal rate (under atmospheric pressure)	91.8	28.0

[a] Throughout this paper pressures noted are gage readings and represent excess over atmospheric pressure.

Although these results are irregular, it will be noted that they show a marked increase over the normal rate of burning 91.8 seconds per meter. In the test which showed the most rapid rate of burning the velocity of combustion through the fuse was found to be increased 161 per cent over the normal rate of burning. Even the piece of fuse burning the slowest shows an increased rate of burning 43.6 per cent over that of normal fuse.

Three samples of fuse were tested at approximately 2 atmospheres (2 kilograms per square centimeter, or 30 pounds per square inch), and in this case the rate of burning was somewhat greater than the average of the former experiments, as will be noted from the following tabulation:

Rate of burning of fuse under 2 atmospheres pressure.

No. of sample.	Rate of burning.	
	Seconds per meter.	*Seconds per foot.*
1	46.9	14.3
2	50.8	15.5
3	53.1	16.2
Average	50.3	15.3
Normal rate (under atmospheric pressure)	91.8	28.0

Eight samples of triple-tape fuse were tested under a pressure of 3 kilograms per square centimeter (45 pounds per square inch), and most interesting results were obtained. A velocity as rapid as 19.7 seconds per meter (6 seconds per foot) was produced in one case, whereas other experiments gave rates of burning varying from this figure to 46.3 seconds per meter (14.1 seconds per foot). The wide variation shown in this experiment is worthy of note. From the variations of the pressure gage as the excess of gas was allowed to escape it was seen, particularly in the case where the fuse burned more rapidly, that the rate of burning was very irregular, and that at times the flame "flashed" through the fuse with considerable rapidity. The degree of opening of the relief valve, which was usually found sufficient to allow the excess gases produced by the combustion of the gunpowder to escape, was for various short intervals of time entirely too small to allow the escape of the large volumes of gas which seemed to be almost instantaneously generated. This fact strongly suggests that some form of instantaneous or extremely rapid combustion of fuse was taking place.

When tested under a pressure of 4 kilograms per square centimeter (60 pounds per square inch) results were obtained which also show wide variations. As difficulties were met in keeping the cylinder tight at pressures higher than these, no further experiments were made.

The results at the pressure just mentioned (4 kilograms per square centimeter, 60 pounds per square inch) are shown in the following tabulation:

Rate of burning of triple-tape fuse under 4 atmospheres pressure.

No. of sample.	Rate of burning.	
	Seconds per meter.	*Seconds per foot.*
1	23.6	7.2
2	33.8	10.3
3	41.0	12.5
Average	32.8	10.0
Normal rate (under atmospheric pressure)	91.8	28.0

Some experiments were made to determine what pressure would be produced in experiments similar to those just mentioned if the relief valve were kept closed during the test, so as to allow the pressure exerted by the gas to increase. A 3-meter length of triple-tape fuse was used, and was ignited while contained within the vessel at an initial pressure of 3 kilograms per square centimeter (45 pounds per square inch). The pressure varied from 3 kilograms per square centimeter (45 pounds per square inch) at the beginning of the experiment to 12 kilograms per square centimeter (180 pounds per square inch) at the end. The rise in pressure was at first fairly uniform, and 75 seconds were required to bring about the initial increase of 1 kilogram per square centimeter. Eighty seconds after igniting the fuse (and 10 seconds before the explosion of the cap showed the flame to have traversed its entire length) the pressure jumped from about 4 kilograms per square centimeter (60 pounds per square inch) to 11 kilograms per square centimeter (165 pounds per square inch), and at the explosion of the cap the pressure rose to 12 kilograms per square centimeter (180 pounds per square inch). The rate of burning for the entire experiment was 29.5 seconds per meter, or 9 seconds per foot, but manifestly at times the fuse flashed, and at such times the rate of burning was much more rapid than the average rate for the whole experiment.

Double-tape fuse, tested in the pressure tank in the manner just described, gave results as follows:

Rate of burning of double-tape fuse in pressure tank.

No. of test.	Initial pressure.	Rate of burning.	
		Seconds per meter.	*Seconds per foot.*
1	1 kg. per sq. cm. (15 lbs. per sq. in.)	68.9	21.0
2	2 kg. per sq. cm. (15 lbs. per sq. in.)	69.5	21.2
3	2 kg. per sq. cm. (30 lbs. per sq. in.)	55.4	16.9
4	do	55.1	16.8
5	3 kg. per sq. cm. (45 lbs. per sq. in.)	48.5	14.8
6	do	33.5	10.2

In test 5 the evolution of gas was very rapid just before the detonator was reached, showing that probably a portion of the fuse "flashed." A result similar in nature, though somewhat more marked in effect, was noted in test 6. The rapid rate of burning in these last two experiments shows clearly the effect due to increased pressure. The fuse used in the above experiments had a normal rate of burning of 102 seconds per meter (31 seconds per foot).

A number of other types of fuse were tested in the pressure tank under conditions similar to those already mentioned. In all of these experiments an increase in the rate of burning was noticed with increased pressure.

The results obtained are shown in the following tabulation:

Rate of burning of various types of fuse under varied pressure.

Kind of fuse.[a]	Pressure.	Rate of burning.	
		Seconds per meter.	*Seconds per foot.*
Type 1	1 kg. per sq. cm. (15 lbs. per sq. in.)	49.8	15.2
	2 kg. per sq. cm. (30 lbs. per sq. in.)	34.4	10.5
	3 kg. per sq. cm. (45 lbs. per sq. in.)	29.8	9.1
	Normal rate of burning 84.2 seconds per meter (25.6 seconds per ft.).		
Type 2	1 kg. per sq. cm. (15 lbs. per sq. in.)	63.6	19.4
	2 kg. per sq. cm. (30 lbs. per sq. in.)	33.8	10.3
	3 kg. per sq. cm. (45 lbs. per sq. in.)	26.8	8.1
	Normal rate of burning 103.8 seconds per meter (31.6 seconds per ft).		
Type 3	1 kg. per sq. cm. (15 lbs. per sq. in.)	57.1	17.4
	2 kg. per sq. cm. (30 lbs. per sq. in.)	50.5	15.4
	3 kg. per sq. cm. (45 lbs. per sq. in.)	36.1	11.0
	Normal rate of burning 82 seconds per meter (25 seconds per ft).		
Type 4	1 kg. per sq. cm. (15 lbs. per sq. in.)	79.7	24.3
	2 kg. per sq. cm. (30 lbs. per sq. in.)	69.9	21.3
	3 kg. per sq. cm. (45 lbs. per sq. in.)	62.3	19.0
	Normal rate of burning 106.3 seconds per meter (32.3 seconds per ft).		
Type 5	1 kg. per sq. cm. (15 lbs. per sq. in.)	80.0	24.4
	2 kg. per sq. cm. (30 lbs. per sq. in.)	67.2	20.5
	3 kg. per sq. cm. (45 lbs. per sq. in.)	60.3	18.4
	Normal rate of burning 111.5 seconds per meter (34 seconds per ft.).		
Type 6	1 kg. per sq. cm. (15 lbs. per sq. in.)	97.4	30.3
	2 kg. per sq. cm. (30 lbs. per sq. in.)	87.9	26.8
	3 kg. per sq. cm. (45 lbs. per sq. in.)	82.6	25.2
	Normal rate of burning 131.5 seconds per meter (40 seconds per ft.).		

[a] Kind of fuse used in above tests: Type 1. Cotton fuse. Type 2. Single-tape fuse. Type 3. White-finished, taped, double-countered fuse. Type 4. White-finished, double-countered, gutta-percha fuse. Type 5. White-finished, double-countered fuse. Type 6. Black-finished, double-countered fuse.

In several of the above tests the phenomenon of "flashing" was noted, particularly at the pressure of 3 kilograms per square centimeter. From the tests made it is clear that the tendency to "flash" becomes much more marked at the high pressures, and at pressures higher than 3 kilograms per square centimeter would probably play a very prominent part in the rate of burning of fuse.

The next experiments were intended to show the pressure that probably is produced when fuse is burned in an ordinary drill hole, tamped in the usual manner. A piece of iron pipe 4 feet long was used as the shot hole, and tests were made in which the pipe was

filled with various stemming materials, such as dried fire clay, wet fire clay, and plaster of Paris. Wide variations in the rate of burning were noted, and were found to depend upon the degree of resistance that was offered to the escape of the gases produced by the combustion of the fuse. In many cases the channel left by the burning of the gunpowder core afforded a sufficient exit for the products of combustion of the fuse, so that little increase in pressure took place, and only a slight increase in the rate of burning of the fuse was brought about, whereas, in other experiments performed under similar conditions there were marked changes in the rate of burning. With dried fire clay, for example, the rate of burning of triple-tape fuse was found to be 97.4 seconds per meter (29.7 seconds per foot), as against a normal rate of 103.8 seconds per meter (31.6 seconds per foot). Hence, under the conditions, the dry fire clay as well as the fuse itself allowed the gases to escape with sufficient readiness to prevent any decided increase in pressure. When moist fire clay was used as stemming there was a considerable increase in the rate of burning of the fuse. When 2 meters of fuse were placed within a tube, as before described, and tamped with moist fire clay (12 to 13 per cent moisture) the rate of burning of triple-tape fuse was increased from 96.4 seconds per meter (29.4 seconds per foot) to 61 seconds per meter (18.6 seconds per foot), or 59.2 per cent. In a second test made under identical conditions a still greater increase in the rate of burning was noted, and 2 meters of fuse tamped with fire clay of the same type as before burned at the rate of 57.5 seconds per meter (17.4 seconds per foot) as against the normal rate of burning of 96.4 seconds per meter (29.4 seconds per foot).

In experiments made to determine the effects of different kinds of stemming, moist fire clay produced the greatest increase in the rate of burning, the results varying from 39 seconds per meter to 62 seconds per meter, as against the normal rate of burning of the fuse used of 84 seconds per meter. Dried sand, moist sand, and dried fire clay, when used as stemming, each produced an increase in the rate of burning of fuse, but the increased rate of burning with these materials was usually not greater that 20 to 30 per cent, whereas with moist fire clay, as has already been noted, the increase was in one case as great as 59 per cent. When a cast of plaster of Paris was used in a similar experiment the rate of burning was found to be greatly increased, a sample of triple-tape fuse burning at the rate of 21 seconds per meter (6.4 seconds per foot) as against the normal rate of burning for the same piece of fuse of 92.5 seconds per meter (28.2 seconds per foot).

The rate of burning of several types of fuse, encased in plaster of Paris, is given in the following table:

Rate of burning of various types of fuse encased in plaster of Paris.

Sample.[a]	Ordinary rate of burning.		Rate of burning in plaster of Paris.	
	Seconds per meter.	*Seconds per foot.*	*Seconds per meter.*	*Seconds per foot.*
A	92.5	28.2	21.0	6.40
B	84.0	25.6	26.2	8.00
C	103.6	31.6	18.9	5.75
D	113.8	34.7	59.1	18.00

[a] Kind of fuse used in above tests: A, triple-tape fuse; B, white-finished, taped, double-countered fuse (brand C); C, double-tape fuse; D, white-finished, taped, double-countered fuse (brand A).

It is of course evident that under actual mining conditions fuse would not be subjected to conditions similar to those produced in these experiments with plaster of Paris. The results are of value, however, in showing the great increase in the rate of burning of fuse under confinement. In a very long bore hole, pressures could be produced—especially if moist fire clay or similar stemming material were used—which would effect a confinement practically as great as in the experiments just mentioned.

Several tests were next made to determine whether fuse could be made to "flash" under ordinary conditions of temperature and pressure, solely by constricting some points in its length. Pieces of fuse of definite length were taken, and by means of pliers were held tightly at a number of points in such a way as to prevent the escape of gas beyond the constriction produced by the jaws of the pliers. In these experiments a somewhat increased rate of burning was noted (82 seconds per meter, or 25 seconds per foot, as against a normal rate of burning of 92.5 seconds per meter or 28.8 seconds per foot), but in no case did the fuse flash entirely through or even for a considerable distance. There was always a sharp report caused by the gases suddenly bursting through the side of the fuse, but this appeared to be simply a local phenomenon. The break produced in the fuse provided at once an exit for the gases sufficient to prevent any further increase in the rate of burning. When constrictions were placed every 2 or 3 centimeters along a piece of fuse the rate of burning was not increased more than about 10 per cent.

Fuse with a dense outer covering or fuse that has been subjected to considerable pressure in the process of manufacture usually shows a greater tendency to "flash" than fuse of other types. Experiments made at the testing station of Gelsenkirchen,[b] Germany,

[b] Heise, Fritz, Traité théorique des explosifs, p. 162.

showed that when certain types of fuse there used were "pinched" strongly at any point until the combustion of the powder had passed the compressed point, the part of the fuse beyond that point would almost invariably explode with a jet of sparks and a strong detonation. At times this explosion would occur in a longer or shorter portion of that part of the fuse, the remainder burning quietly. In some cases the explosion extended clear to the end of the fuse, a distance of 1 meter. A number of types of American fuse were tested as above described, but the results of the experiments indicate that no type of fuse in common use in this country will "flash" for any distance under these conditions. It seems probable that the fuse used abroad may differ in this respect from fuse of American make, although, as has been previously mentioned, at somewhat increased pressures the phenomenon of "flashing" becomes pronounced in most types of fuse.

INFLUENCE OF TEMPERATURE.

When tape fuse is heated the tar or asphalt composition used for waterproofing tends to become fluid. At ordinary temperatures the viscosity of the waterproofing compound is such that there is little or no tendency for the compound to be taken up by capillarity by the fibers of the jute or hemp cords surrounding the powder core. But as the temperature rises the waterproofing compound becomes less viscous, and the fibers of the wrapping about the powder core soon become saturated. When considerable waterproofing compound is present, as in types of fuse particularly designed for impermeability to water, the fluid waterproofing material extends completely to the powder core and tends, partly or wholly, to agglomerate the separate grains of powder into a solid mass. Even when only a small amount of waterproofing compound has thus extended through to the powder train there appears to be a decided change in the rate of burning of the fuse. When increasingly large amounts of asphalt composition have reached the powder core the change in the rate of burning becomes still more marked, and when tape fuse has remained for a considerable length of time at an elevated temperature the amount of waterproofing composition that reaches the powder train will often be so great as to completely agglomerate the powder and entirely prevent the flame from traversing the fuse.

To outline roughly the change in the rate of burning that results from the heating of triple-tape fuse, two lengths were taken from a single roll of the fuse. One of these lengths was kept at a temperature of 60° C. (140° F.) for one hour, and the other was kept at a temperature of 90° C. (194° F.) for the same length of time. The fuse that had been kept at a temperature of 60° C. burned at a rate of 98.4 seconds per meter (30 seconds per foot), and the length that had

been kept at a temperature of 90° C. burned at the rate of 351 seconds per meter (98 seconds per foot). These results show that exposure to a temperature of 90° C. for one hour causes a marked retardation in the rate of burning of triple-tape fuse, the time required for the flame to traverse a given length of fuse so treated being more than three times as long as the time required for the flame to traverse the same length of normal fuse.

Even fuse that had been kept at 60° C. (140° F.) burned at a rate somewhat slower than the normal. Experiments were made with a number of lengths of triple-tape fuse which had been kept at a carefully regulated temperature of 60° C. for a number of hours. The results of these experiments were as follows:

Rate of burning of triple-tape fuse heated at 60° C.

Number of hours heated.	Rate of burning.	
	Seconds per meter.	*Seconds per foot.*
1	96.1	29.3
2	97.4	29.7
3	98.4	30.0
4	99.4	30.3
5	101.7	31.0
6	101.7	31.0
7	101.7	31.0
8	102.7	31.3
9	101.7	31.0
10	105.0	32.0

Since prolonged heating, even at a temperature as low as 60° C., causes a retardation in the rate of burning of fuse, it is obvious that in blasting operations care should be taken not to store fuse in too warm a place, as near boilers or steam pipes. Fuse may be seriously damaged by being kept in a tin box exposed to the direct rays of the sun, because the interior of the box may reach a temperature many degrees higher than the temperature of the surrounding air. A black metal box exposed to the rays of the sun in an open quarry has been found to reach a temperature high enough to modify greatly the rate of burning of lengths of fuse kept therein.

When fuse is cooled below the normal temperature, as when used out of doors upon a cold day, the rate of burning differs from the normal rate. A series of tests made by placing lengths of fuse out of doors at various temperatures (equal lengths cut from the same rolls being kept at normal temperature) enabled the effects of small changes of temperature below the normal to be determined. For example, a 3-meter length of triple-tape fuse that had been exposed for about three hours to a temperature of —4° C. (25° F.) burned at the rate of 84.3 seconds per meter (25.7 seconds per foot), whereas a similar length cut from the same roll of fuse and kept at the laboratory temperature of 18° C. (64.5° F.), burned at the rate of 88.6 seconds per meter (27 seconds per foot).

It will be noted that exposure to a fairly low temperature for a short time tends to accelerate slightly the rate of burning of fuse, and this effect is no doubt the result of the increased firmness of the tar and asphalt waterproofing, which tends to become more rigid at low temperatures. When fuse is exposed to a decidedly low temperature for a considerable time just the opposite result is reached, because the tar or asphalt becomes so brittle as to break readily under even the slight pressure produced by the escaping gases and allows the gases more ready access to the outside air.

The following table shows the results of two experiments made with lengths of triple-tape fuse that had been kept at a temperature of about −10° C. (14° F.) for two days and with similar lengths of fuse cut from the same roll but kept at the laboratory temperature:

Effect of varying temperature on rate of burning of triple-tape fuse.

No. of sample.	Rate of burning.			
	At temperature of 18° C. (64.5° F.).		At temperature of −10° C. (14° F.).	
	Seconds per meter.	*Seconds per foot.*	*Seconds per meter.*	*Seconds per foot.*
1	97.4	29.7	141.4	43.1
2	93.5	28.5	136.4	41.6

It is evident from the above table that the increased brittleness at low temperatures of the tar or asphalt in triple-tape fuse has marked influence in determining the rate of burning. However, this matter is not of great importance, since in nearly all mines the temperature at the working face is constant throughout the year. In quarries, however, fuse probably burns much more slowly during very cold weather, and the amount of handling that the fuse receives while it is cold (and therefore while the tar is brittle) also influences its rate of burning.

Further experiments with triple-tape fuse at high temperatures showed that the rate of burning is retarded from a normal rate of 96.1 seconds per meter (29.3 seconds per foot) to a rate of 22.9 second per meter (70 seconds per foot) by heating four hours at 80° C. (176° F.). Fuse heated to this temperature often failed to burn completely through, and in several of the samples tested the powder grains were so agglomerated by saturation with the fluid waterproofing compound as to prevent entirely the burning of the powder core.

Triple-tape fuse that had been heated for five hours at 80° C. burned at rates varying from 363.1 seconds per meter (110.7 seconds per foot) to 411 seconds per meter (125.3 seconds per foot), or over four times the normal time of burning. Only comparatively

short lengths of the fuse would burn, the stoppages due to complete agglomeration of the powder being very frequent. In tests of types of fuse containing little or no tar or asphalt (cotton fuse, etc.) it was found that temperatures of 70° C. (158° F.), or less, had little or no influence on the rate of burning. This result was to be expected, because, as already noted, it is the increased fluidity of the tar or asphalt waterproofing of triple-tape and similar fuses that brings about the retardation in burning through agglomeration of the powder grains. With fuse containing considerable amounts of waterproofing material wide variations were produced by heating to temperatures of 100° C. or less.

In the following table the results of several such tests are given in seconds per meter:

Rate of burning of triple-tape fuse heated at 80° C.

Name of sample.[a]	Time of heating.					
	1 hour.	2 hours.	3 hours.	4 hours.	5 hours.	6 hours.
A	82.0	82.0	78.7	78.7	78.7	78.7
B	275.5	229 6	(b)	210.0	213.2	(b)
C	685.5	639.6	636.3	692.1	744.6	629.7
D	246.0	416.6	724.9	626.5	629.7	744.6
E	(b)	377.2	597.0	672.4	597.0	597.0

[a] Kind of fuse used: A, cotton fuse; B, single-tape fuse; C, white-finished, double-countered, gutta-percha fuse; D, white-finished, double-countered fuse; E, black-finished, double-countered fuse.
[b] Failed to burn through.

These tests, some of which show rates of burning almost ten times as slow as the normal rate, demonstrate how great may be the "slowing down" of fuse that has been exposed even for a short time to a high temperature. The following table shows the variations in several types of fuse heated at different temperatures for one hour:

Effect of heating for one hour on rate of burning of fuse.

Name of sample.[a]	At normal temperature (18° C.).		At 75°–80° C.		At 85°–90° C.		At 115°–125° C.	
	Seconds per meter.	*Seconds per foot.*	*Seconds per meter.*	*Seconds per foot.*	*Seconds per meter.*	*Seconds per foot.*	*Seconds per meter.*	*Seconds per foot.*
A	82.0	25	82.0	25	78.7	24	82.0	25
B	101.7	31	91.8	28	95.1	29	485.4	148
C	105.0	32	121.4	37	206.6	63	531.4	162
D	114.8	34	134.5	41	190.2	58	672.4	205
E	131.2	40	124.6	38	223.0	68	626.5	191
F	100.0	30	101.0	31	105.0	32	335.0	102
G	101.0	31	101.0	31	206.0	63	(b)	(b)

[a] Kind of fuse used: A, cotton fuse; B, single-tape fuse; C, white-finished, double-countered, gutta-percha fuse; D, white-finished, double-countered fuse; E, black-finished, double-countered fuse; F, white finished, taped, double-countered fuse (brand A); G, double-tape fuse.
[b] Failed to burn through.

INFLUENCE OF MOISTURE.

If a small amount of moisture gains access to the powder core of fuse, it tends to retard the rate of burning of the fuse; if a large amount of moisture gets within the powder core, it will probably entirely prevent burning. If moisture has gained access to fuse, and the fuse has been dried in order to reduce the moisture present to about the normal figure, the rate of burning of the fuse is generally slower than was the original rate, and the tendency of the fuse not to burn completely through is pronounced.

Some experiments made by French investigators show that the rate of burning of fuse that has been stored in a dry place may differ 45 per cent from the rate of burning of fuse that has been stored in a damp place.[a]

Tests of identical character were made by the writers with several types of American fuse, but the changes in the rate of burning, even after storage for a considerable length of time, were not so great as those found by the French investigators. It is to be noted that most of the fuse made in France is similar to that which is used in this country for comparatively dry work, and this fact probably accounts for the divergence in results.

Experiments with pieces of fuse that had been subjected to mechanical injury (for instance, a cut such as would be made by the fuse striking a sharp edge of the tin lining of cases for export shipment), exposed to a moist atmosphere for 10 days, and then carefully dried at about 50° C., showed results decidedly different from those obtained with pieces of the same fuse which had not been so treated. In the case of triple-tape fuse the rate of burning varied from 98 seconds per meter (30 seconds per foot) to 115 seconds per meter (35 seconds per foot), as compared with a normal rate of burning for the same fuse of 92 seconds per meter (28 seconds per foot). With double-tape fuse the rate of burning was altered from 103 seconds per meter to about 130 seconds per meter, and with other types of fuse proportional variations were produced. In all cases it was noted that the effect of exposing the fuse to moisture, even when followed by careful drying, was to materially retard the rate of burning of the fuse. In no case was an acceleration noted, and whenever the fuse was exposed to moisture for any considerable length of time without being carefully dried afterwards, there was an entire failure of the fuse to burn completely through.

Because the waterproofing of fuse is quite as effective in keeping in water that has once gained access to fuse, as in keeping out external water, obviously fuse that has once become wet is difficult to dry thoroughly. Hence, both because of the variations that are pro-

[a] Loiret and Aron, Eng. and Min. Jour., vol. 88, Nov. 27, 1909, p. 1074.

duced in the rate of burning of such fuse after becoming moist and because of the greatly increased liability of misfires through such fuse failing to burn through at all, fuse that has been stored in a very damp place or has in any manner become wet should clearly not be used in mining operations.

Types of fuse differ greatly in regard to their ability to withstand exposure to moisture. "Cotton" fuse and "hemp" fuse are not designed for use in wet ground, and accordingly these types of fuse show little resistance to moisture. Ability to withstand water varies in accordance with the nature of the covering or the protection that is given to the "wrapped core." Gutta-percha fuse, triple-tape fuse, and taped, double-countered fuse show the highest resistance to water, and under favorable conditions any of these types of fuse will stand immersion for a number of hours.

In the course of the present study a convenient means was employed to determine the comparative water-resisting qualities of various types of fuse. A number of pieces were cut from rolls of each of the types of fuse to be tested, and one end of each of these lengths was dipped for a moment in warm pine tar. The pieces (about 40 centimeters long) were then placed in a vertical position in jars containing water that covered all but about 5 centimeters of the fuse. A considerable number of pieces of fuse having been so arranged, samples were withdrawn at fixed intervals, a short length of each at the end protected by the tar or asphalt composition was cut off, and the pieces of fuse were then lighted to determine whether they would burn completely through. Testing numerous pieces of fuse in this manner enables one rapidly to determine for different types their relative resistance to water, and by a slight modification in this method (such as covering both ends of the short length of fuse with asphalt and later cutting off a few inches from each end) the fuse can be tested under any required condition of pressure. The results obtained relative to the resistance to water of the various types of fuse lie without the scope of this paper and are not given for that reason, but the method described is a convenient one for determining the thoroughness of the waterproofing of different types of fuse.

INFLUENCE OF MECHANICAL INJURY.

When fuse is under pressure sufficient to prevent the escape of the products of combustion of the gunpowder, the rate of burning is greatly increased. If fuse is compressed by a wedge or by tamping, the rate of burning may be increased 500 per cent.[a] Experiments to determine the changes in the rate of burning brought about by crushing and pressing fuse within pipes or other restricted spaces have also been mentioned in the literature.[b]

[a] Loiret and Aron, Eng. and Min. Jour., vol. 88, Nov. 27, 1909, p. 1074.
[b] Eng. and Min. Jour., vol. 86, Oct. 24, 1908, p. 823.

In experiments made in connection with the present report, pieces of fuse 2 meters in length were forcibly inserted, with consequent bending, coiling, and crushing, into a pipe 5 centimeters (2 inches) in diameter. The normal rate of burning of this fuse was 92 seconds per meter (28 seconds per foot), but the pieces that had been crushed into the pipe burned at the rate of 79 seconds per meter (24 seconds per foot).

Some tests of fuse that had been subjected to such pressure as is produced by pounding, hammering, etc., gave interesting results; several lengths of fuse that had been thus treated showed a more rapid rate of burning than was noted even in the experiments relating to the influence of pressure. However, a moderate amount of mechanical injury, such as rolling or crushing, provided it is not sufficient to rupture the fabric of the fuse, usually has a slight retarding action on the rate of burning.

A piece of fuse that had been pounded with an ordinary hammer showed a rate of burning of 13 seconds per meter (4 seconds per foot). The normal rate of burning of this fuse was 82 seconds per meter (25 seconds per foot). A similar piece, which had been struck lighter blows and showed no abrasion of the outer wrappings, burned at the normal rate for about 50 centimeters and then "flashed." The rate of burning of this fuse was 59 seconds per meter (18 seconds per foot). A piece of fuse that had been compressed by pounding at nine points along its length, the spaces compressed being 5 centimeters long and separated by 3-centimeter intervals, "flashed" at seven of the nine compressed areas, and showed a rate of burning of 69 seconds per meter (21 seconds per foot). The normal rate of burning of this fuse was the same as that used in the former experiment, and the change in the rate of burning from 82 seconds per meter (25 seconds per foot) to 69 seconds per meter (21 seconds per foot) was due to the "flashing" at the compressed areas.

When fuse was subjected to a rather rough pounding with a hammer, the rate of burning was very rapid, and in these experiments a rate of burning of 10 seconds per meter (3 seconds per foot) to 23 seconds per meter (7 seconds per foot) was noted. In one experiment in which a piece of fuse had been pounded until it was decidedly flattened the remarkable rate of burning of 3 seconds per meter (1 second per foot) was observed. As such fuse can be considered to be practically "instantaneous," the use of fuse that has been injured by falling rocks, blasts, etc., is consequently dangerous. The length of fuse customarily used in lighting "adobe" shots is about 1 meter, or 3 feet, and if this length of fuse were to burn in 3 or 4 seconds instead of in its normal time of about 90 seconds there would evidently be great possibility of accident. The falling of rock or similar causes would clearly not subject fuse to such a strain or

pressure as was used in the above experiment, but those portions of the fuse which might be subjected to the direct blow of a falling rock or other similar source of pressure would burn with a rapidity comparable to that noted in the experiment just mentioned. When a number of adobe shots are to be lighted at one time, difficulty in the lighting of one or two of the pieces of fuse, frequently sufficient to cause a delay of 15 or 20 seconds, may manifestly become the cause of accident.

When fuse is sharply bent, as by drawing it around a rod, or when portions of fuse are injured by cutting, as by slashing with a knife, the rate of burning is only slightly affected. A piece of fuse 1 meter in length was drawn back and forth several times over a piece of pipe about 2 centimenters (0.75 inch) in diameter and the time of burning was found to be normal. Even when a similar experiment was tried with a smaller pipe the result was similar, and no decided variation from normal was noted.

In seeking an explanation of the rapid burning in a number of experiments in which fuse had been pounded, etc., several samples of such fuse before being lighted were extracted with carbon bisulphide until all the tar and asphalt had been removed and were then examined. In this way the exact conditions of the tape, wrappings, and the protected core could be ascertained. In every case the tape was found to be torn as a result of the strain set up by pounding. Clearly, therefore, the great rapidity of burning of fuse that had been so pounded was due in part to the weakened condition in a direction parallel with the length of the fuse, as well as to the fact that the fuse so injured could more readily provide open spaces by reason of the pressure of the gases produced by combustion, thus enabling the flame to be projected within the fuse for a considerable distance along the powder core.

Although not properly to be classed with the other types of mechanical injury already enumerated, the action of oil upon fuse is a factor that deserves consideration. Experiments made with various kinds of oil and grease showed that not only the lighter grades of fuse but also the waterproofed types were readily penetrated by oily substances, and fuse that had been in contact with oil or grease for a considerable length of time would often fail to burn completely through. The lighter lubricating oils brought about deleterious results more readily than the heavier oils.

PRACTICAL CONCLUSIONS.

It is important that time fuse should have a uniform rate of burning, and in almost all blasting operations the fuse that is used is assumed to burn in a regular and uniform manner. When fuse

has been subjected to such conditions as produce acceleration or retardation in its rate of burning it becomes dangerous. Acceleration of the rate of burning increases the liability of a shot going off before the miner has left the face; retardation increases the chance of the flame in the fuse progressing so slowly that the miner will be injured by a delayed shot when he returns to the working face. All conditions that bring about any marked change in the rate of burning of fuse are dangerous, and from a study of the list of accidents in mines and quarries each year injury and loss of life are seemingly often brought about by such conditions.

Under ordinary conditions nearly all types of fuse show great uniformity in their rate of burning. Practically all types of fuse examined in connection with the preparation of this report had a total variation in their rate of burning under normal conditions of less than 20 per cent and all would have been passed under the allowance of "no variation greater than 10 per cent above or 10 per cent below the average rate of burning."

Under the influence of pressure practically all types of fuse are subject to wide variation in their rate of burning. Such pressure as can readily be produced by the confinement of the gases evolved by the burning fuse itself is sufficient to increase the normal rate of burning from 92.5 seconds per meter (28.2 seconds per foot) to 21 seconds per meter (6.4 seconds per foot). Thus, even confinement will cause fuse to burn from three to four times as rapidly as its normal rate. In experiments made with fuse confined by stemming of various kinds wide variations in the rate of burning were noted, and whenever lengths of fuse are confined by stemming or other materials impervious to gas, a sufficient length of the fuse should be used to allow for the increased rate of burning due to the pressure produced by the evolved gases.

High temperature causes a marked retardation in the rate of burning of fuse, and storage for even a short period of time near boilers, or wherever the temperature may be high, is sufficient either to cause "misfires," or to retard the rate of burning of the fuse so much as to greatly increase the liability to "holdbacks," delayed shots, etc. It is probable that many of the difficulties that are sometimes encountered in regard to fuse burning too slowly and causing delayed shots are due, in part at least, to such fuse having been kept in too warm a place. Fuse that is not intended for use in wet places (cotton fuse, etc.), does not suffer marked change in its normal rate of burning by reason of the effect of high temperatures, whereas the more completely waterproofed types of fuse show increasingly great effects from heat. Even exposure to comparatively low temperatures for considerable lengths of time causes marked retardation in the rate

of burning of such fuse, and exposure to a fairly high temperature for even a short length of time may cause certain types of fuse to burn from three to five times as slowly as their usual rate. To insure the best results, fuse should always be protected from extremes of temperature.

Climatic conditions affect to a considerable extent the rate of burning of the less waterproof types of fuse. Damp fuse burns more slowly than normal fuse, and fuse that has been wet and then thoroughly dried tends to burn at a rather slow rate, and may even cause delayed shots by smoldering for a considerable time. Fuse containing several wrappings of tape saturated with tar or asphalt resists moisture to a considerable extent, and may be used for firing shots under water, provided the fuse is not allowed to remain too long a time in contact with water before the shot is fired.

It is, of course, evident that when these waterproof types of fuse do become wet, whether through storage for a long time in a damp place or through exposure to water after the protecting layers of asphalt or gutta-percha are mechanically abraded or injured in any other way, they are more difficult to dry out than are other types of fuse, and are more liable to burn at a rate slower than the normal rate.

Fuse that has been subjected to actual mechanical injury, particularly to hammering or pounding or the blows of falling rock, etc., has a greatly increased rate of burning, and sometimes burns so rapidly as to be almost instantaneous in its action. The mere bending, coiling, and twisting of fuse, such as would be brought about by forcibly placing within a bore hole a length of fuse considerably greater than the depth of the bore hole, does not produce any marked change in the rate of burning, but pounding or direct abrasion of fuse greatly increases that rate. Fuse that has been injured by severe abrasion or by too great pressure from any cause should not be used in any work where adjustment of the rate of burning is desired.

As a final summary it may be stated that ordinary fuse may under some conditions burn as fast as 3 seconds per meter (1 second per foot), and under other conditions it may burn as slowly as 745 seconds per meter (227 seconds per foot). The former rate is more than 200 times as fast as the latter, and each is widely removed from the normal rate of burning of similar brands of fuse. Hence, the condition and past history of any roll of fuse is an important matter, and in mining and blasting operations the safety of the miner demands that only fuse that has been carefully stored and kept from unfavorable conditions shall be used.

PUBLICATIONS ON MINE ACCIDENTS AND TESTS OF EXPLOSIVES.

The following Bureau of Mines publications may be obtained free by applying to the Director, Bureau of Mines, Washington, D. C.:

BULLETIN 17. A primer on explosives for coal miners, by Charles E. Munroe and Clarence Hall. 1911. 61 pp. 10 pls. Reprint of United States Geological Survey Bulletin 423.

BULLETIN 20. The explosibility of coal dust, by George S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 1911. 205 pp. 14 pls. Reprint of United States Geological Survey Bulletin 425.

BULLETIN 26. Notes on explosive mine gases and dusts, with particular reference to explosions in the Monongah, Darr, and Naomi coal mines, by R. T. Chamberlin. 67 pp. Reprint of United States Geological Survey Bulletin.

MINERS' CIRCULAR 2. Permissible explosives tested prior to January 1, 1911, and precautions to be taken in their use, by Clarence Hall. 1911. 12 pp.

MINERS' CIRCULAR 3. Coal-dust explosions, by George S. Rice. 1911. 22 pp.

MINERS' CIRCULAR 4. The use and care of mine-rescue breathing apparatus, by J. W. Paul. 1911. 24 pp.

MINERS' CIRCULAR 5. Electrical accidents in mines; their causes and prevention, by H. H. Clark. 1911. 10 pp.

TECHNICAL PAPER 4. The electrical section of the Bureau of Mines; its purpose and equipment, by H. H. Clark. 1911. 13 pp.

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